METHOD AND APPARATUS FOR OPTIMIZING A JPEG IMAGE USING REGIONALLY VARIABLE COMPRESSION LEVELS

FIELD

The present invention relates to a method and apparatus for optimizing a JPEG image using regionally variable compression levels.

BACKGROUND

Compression is a useful method for reducing bandwidth consumption and download times of images sent over data networks. A variety of algorithms and techniques exist for compressing images. JPEG, a popular compression standard that is particularly good at compressing photo-realistic images, is in common use on the Internet. This standard, defined in "JPEG Still Image Data Compression Standard", by W.B. Pennebaker and J.L. Mitchell, Chapman & Hall, 1992, is based on a frequency domain transform of blocks of image coefficients. As seen in Figure **1**, JPEG calls for subdividing an image frame **12** into 8x8 pixel blocks **11** and at box **16** transforming the array of pixel values in each block **11** with a discrete cosine transform (DCT) so as to generate 64 DCT coefficients corresponding to each pixel block **11**. The coefficients for each block **11** are quantized in quantization block **20** using a 64 element quantization table **24**. Each element of table **24** is an integer value from 1 to 255, which specifies the step size of the quantizer for the corresponding DCT coefficients. The quantized coefficients for each block are entropy encoded in entropy coding box **28**, which performs a

lossless compression. The entropy encoder **28** is coupled to the output of the quantizer **20** from which the former receives quantized image data. Standard JPEG entropy coding uses either Huffman coding or arithmetic coding using either predefined tables or tables that are computed for a specific image.

The JPEG compressed image data is decompressed by the bottom circuit of Figure **1** by being first passed through an entropy decoder **30**. Next inverse quantization in block **32** using quantization table **34** is performed. Finally the inverse DCT transform block **36** performs an inverse DCT operation to produce the image pixel intensity data.

More specifically, the discrete cosine transform block uses the forward discrete cosine function (DCT) to transform the image pixel intensity A(x,y) to DCT coefficients Y_{mn} as follows:

$$Y_{mn} = 1/4\ C(m)C(n)\left[\sum_{x=0}^{7}\sum_{y=0}^{7} A(x,y)\cos\frac{(2x+1)m\pi}{16}\cos\frac{(2y+1)n\pi}{16}\right]$$

where C(m) and $C(n)=1/\sqrt{2}$ for m,n=0, and C(m) and C(n)=1 otherwise.

The next step is to quantize the DCT coefficients using a quantization matrix, which is an 8 x 8 matrix of step sizes with one element for each DCT coefficient. A tradeoff exists

between the level of image distortion and the amount of compression, which results from the quantization. A large quantization step produces large image distortion, but increases the amount of compression. A small quantization step produces lower image distortion, but results in a decrease in the amount of compression. JPEG typically uses a much higher step size for the coefficients, which correspond to high spatial frequency in the image, with little noticeable deterioration in the image quality because of the human visual system's natural high frequency rolloff. The quantization is actually performed by dividing the DCT coefficient Y_{mn} by the corresponding quantization table entry Q_{mn} and the result rounded off to the nearest integer according to the following:

$$T_{mn} = \mathrm{round}(Y_{mn}/Q_{mn})$$

to give a quantized coefficient T_{mn}. This type of quantizer is sometimes referred to as a midtread quantizer. An approximate reconstruction of Y_{mn} is effected in the decoder by multiplying T_{mn} by Q_{mn} to obtain a reconstructed Y_{mn}. The difference between Y_{mn} and Y_{mn} represents lost image information causing distortion to be introduced. The amount of this lost information depends on the magnitude of Q_{mn}.

In the case of an image with multiple color channels, the aforementioned steps are applied in a similar fashion to each channel independently. In some cases, some of the color channels

may be sub-sampled to achieve greater compression, without significantly altering the quality of the image reconstruction.

The quantization step is of particular interest since this is where information is discarded from the image. Ideally, one would like to discard as much information as possible, thereby reducing the stored image size, while at the same time maintaining or increasing the image fidelity. Within the standard there is no prescribed method of quantizing the image, but there is nonetheless a popular approach used in the software of the Independent JPEG Group (ISO/IEC JTC1 SC29 Working Group 1), and employed extensively by the general community. This method involves scaling a predetermined quantization table (calculated from statistical importance of basis vectors over a large set of images) by a factor dependent on a user-set quality, which lies in the range 1-100. This method yields good results on average, but is based on statistical averages over many images, and doesn't address global image characteristics, let alone local characteristics.

V. Ratnakar and M. Livny. "RD-OPT: An efficient algorithm for optimizing DCT quantization tables." Proceedings DCC'95 (IEEE Data Compression Conference), pages 332-341, 1995 (and also U.S. Patent No. 5,724,453) describe a rate-distortion dynamic programming optimization technique to reduce distortion for a given target bit-rate, or reduce bit-rate for a given target distortion. This reference uses "Mean Squared Error" as a

measure of distortion and introduces some novel techniques for estimating bit-rate that improve the computational efficiency of the calculation. This algorithm is designed to calculate a single quantization table Q for each channel of the image, and it is based solely on global aggregate statistics. Also it does not take into account varying local image statistics. Moreover the method is computationally expensive. There exists another technique, which simultaneously optimizes the quantization and entropy encoding steps yielding a completely optimum JPEG file stream. This technique, however is extremely slow and unrealistic for real-time JPEG optimization.

US Patent No. 5,426,512 entitled "Image data compression having minimum perceptual error" uses a rate-distortion dynamic programming optimization technique to reduce distortion for a target bit-rate, or reduce bit-rate for a target distortion. This technique is very similar in concept to V. Ratnaker et al., except that the latter uses a "perceptual error" measure which attempts to mimic the eye's sensitivity to error. This algorithm is designed to calculate a single quantization table Q for each plane of the image, and it is based solely on global aggregate statistics, and it does not take into account varying local image characteristics.

US Patent No. 5,883,979 entitled "Method for selecting JPEG quantization tables for low bandwidth applications" is directed mainly at preserving text features in JPEG images at

very low bit-rates. It uses image analysis based on global statistics to determine which DCT basis vectors are more visually important to the image, and weights them accordingly in the quantization table. Again, this algorithm is based on global statistics and also it is geared specifically for preserving textual data in JPEG images.

Ideally, one would like to have an optimal quantization table for every significantly different region of the image (a technique adopted for example in MPEG), which would then allow one to increase image fidelity as a function of file size; this technique of using different quantization tables for different areas of an image is generally referred to as variable quantization. In variable quantization, the figures of merit in question are image quality (distortion) and output file size (rate). The problem is then to decrease image distortion for a target rate, or to decrease rate for a target distortion. Of particular interest is the latter, since it has direct application in minimizing bandwidth usage for images which are sent over computer networks. This also reduces the time to transmit the image, which is important when the network path includes slow speed links.

It is preferred that any technique for quantizing an image also be computationally efficient, especially when the quantization is performed on images which are generated dynamically, or images which cannot be stored in a caching

system. If the quarantization is too slow, then any transmission time benefit realized from the reduction in rate is effectively annulled by the latency introduced in the quantization computation.

Accordingly, it is an object of the invention to provide a method for quantizing a JPEG image, which offers many of the benefits of variable quantization and is computationally efficient, while conforming to the widely used JPEG standard.

SUMMARY OF THE INVENTION

According to the present invention there is provided a method, which is directed towards regionally variable levels of compression. The method is directed to JPEG compression of an image frame divided up into 8 x 8 pixel blocks B_{ij} where i, j are integers covering all of the blocks in the image frame. The method includes forming a discrete cosine transform (DCT) of each block B_{ij} of the image frame to produce a matrix of blocks of transform coefficients D_{ij}. Next a visual importance, I_{ij}, is calculated for each block of the image, based upon assigning zeros for flat features and values approaching unity for sharply varying features. A global quantization matrix Q is then formed such that the magnitude of each quantization matrix coefficient Q_{ij} is inversely proportional to a visual importance I_{ij} of a corresponding DCT basis vector to the image. This local visual

importance is used during the quantization stage, where for regions of lower detail, more data is discarded, resulting in more aggressive compression. In the quantization stage the transform coefficients are quantized by dividing them by a factor S_{ij} Q, where S_{ij} is a linear scaling factor, to create a JPEG image file. This algorithm is unique in that it allows for the effect of variable-quantization to be achieved while still producing a file which conforms to the JPEG standard.

The visual importance, I_{ij} may be determined by discrete edge detection and summation of transform coefficients. This determination of I_{ij} may include creating a 24 x 24 matrix of image pixels of DCT coefficients centered on a block B_{ij}, where i and j =1, 2,...8. The center 10 x 10 matrix of the 24 x 24 matrix may be convolved with an edge tracing kernel. The matrix values of the convolved matrix may be summed, and the summed value normalized to produce a visual importance, I_{ij}.

The quantization matrix, Q, may be formed by calculating an 8 x 8 matrix A by calculating matrix elements A_{mn} according to the formula:

$$A_{mn} = \underset{V(i,j)}{\bullet} I_{ij} (B_{ij})_{mn}.$$

Elements Q_{mn} of Q may then be calculated according to the formula:

$$Q_{mn} = \max(A_{mn})/A_{mn}$$

and scaling values of Q_{mn} for all values of (m,n) except (0,0) in order to minimize the error between Q and a standard JPEG quantization matrix.

The linear scaling factor S_{ij} may be set equal to $l_{ij}(S_{max}-S_{min}) + S_{min,}$ where S_{max} and S_{min} are user selected.

Quantizing the blocks of DCT coefficients D_{ij} to produce quantized DCT coefficients T_{ijm}, where m and n refer to row and column, respectively, in each of the blocks may be accomplished by applying the formula.

T_{ijmn} = round $(D_{ijmn}/(S_{min}*Q_{mn}))$, where round denotes rounding to the nearest integer,

and if $T_{ijmn} > 0$

calculate round $(D_{ijmn} / (S_{ij}*Q_{mn}))$ and if equal to zero then set $T_{ijmn} = 0$, otherwise if

$(abs(D_{ijmn}) - (2\text{^}(ceil(lg(abs(D_{ijmn}) +1))-1)-1))$

$<= abs(D_{ijmn}-Q_{mn}*S_{ij}*round\ (D_{ijmn} / (S_{ij}*Q_{mn})))$

then

$T_{ijmn} = sign(D_{ijmn})*(2\text{^}\ (ceil(lg(abs(D_{ijmn})+1))-1)-1).$

According to another aspect of the invention there is provided a method of JPEG compression of a colour image represented by channels Y for greyscale data, and U and V each for colour, which comprises shrinking the colour channels U and V by a fraction of their size, forming a discrete cosine transform (DCT) D_{ij} for each block B_{ij} of each of channels Y, U and V and calculating a visual importance, I_{ij}, for each Y channel block of each image and setting I_{ij} = max{ I_{ij} values for corresponding Y channel blocks} for blocks in the U and V channels. A global quantization matrix Q is formed for the Y channel block and one for channels U and V combined such that a magnitude of each quantization matrix coefficient Q_{ij} is inversely proportional to a visual importance I_{ij} to the image of a corresponding DCT basis vector. Next the transform coefficients for each of the Y, U and V channels are quantized by dividing them by a factor S_{ij} Q', where S_{ij} is a linear scaling factor for each of channels Y, U and V and Q' is the quantization table for the associated channel being quantized. Finally, the quantized coefficients T_{ijmn} and Q'*S_{min} are entropy encoded, where S_{min} is a user selected minimum scaling factor for each of channels Y, U, and V, to create a JPEG image file for each of channels Y, U and V.

Preferably, the shrinking factor is 1/2.

In another aspect of the invention there is provided an apparatus for JPEG compression of an image frame divided up into a plurality of non-overlapping, tiled 8 x 8 pixel blocks B_{ij} where

i, j are integers covering all of the blocks in the image frame. The apparatus includes a discrete cosine transformer (DCT) operative to form the deiscrete cosine transform of each block B_{ij} of the image frame to produce a matrix of blocks of transform coefficients D_{ij}, a visual importance calculator operative to calculate the visual importance, I_{ij}, for each block of the image, based upon assigning zeros for flat features and values approaching unity for sharply varying features and a global quantization matrix calculator operative to calculate the global quantization matrix, Q, by one of

(i) selecting a standard JPEG quantization table and

(ii) selecting a quantization table such that the magnitude of each quantization matrix coefficient Q_{ij} is inversely proportional to the importance in the image of the corresponding DCT basis vector.

A linear scaling factor calculator determines a linear scaling factor, S_{ij}, defining bounds over which the image is to be variably quantized based on user established values of S_{max} and S_{min}. A quantizer is operative to divide the transform coefficients, D_{ijmn}, by a value equivalent to dividing them by a factor S_{min}*Q, where S_{min} is a user selected minimum scaling factor, and an entropy encoder encodes the quantized coefficients T_{ijmn} and Q *S_{min} to create a JPEG image file.

BRIEF DESCRIPTION OF THE DRAWINGS

Further features and advantages will be apparent from the following detailed description, given by way of example, of a preferred embodiment taken in conjunction with the accompanying drawings, wherein:

Fig. 1 is a schematic diagram showing a conventional JPEG system;

Fig. 2 is a flowchart showing the sequence of steps in the algorithm; and

Fig. 3 is a schematic diagram of the JPEG image compressor.

DETAILED DESCRIPTION WITH REFERENCE TO THE DRAWINGS

An image frame is selected at step **40**. The image frame is divided into non-overlapping tiled 8x8 pixel blocks B_{ij} at step **42** according to the JPEG standard.

For each 8x8 block B_{ij} in the image frame, a visual image importance I_{ij} is calculated at step **44**. Note that the actual measure of visual importance is not important to the outline of the algorithm. The I_{ij} values exhaustively cover the range [0,1], and are a measure of how aggressively the block can be quantized. A value of $I_{ij} = 0$ indicates that the visual appearance of the block is rather insensitive to the level of

quantization, and a value of $I_{ij} = 1$ indicates that the visual appearance of the block is very sensitive to the level of quantization.

One method of selecting the visual importance I_{ij} is based on a discrete edge-detection and summation technique. Consider a 24 x 24 window W_{ij} on the image defined by the nine image blocks, $B_{i-1,j-1}$, $B_{i,j-1}$, $B_{i+1,j-1}$, $B_{i,j}$, $B_{i+1,j}$, $B_{i-1,j+1}$, $B_{i,j+1}$, $B_{i+1,j+1}$. This window is centered around the block B_{ij}. The nine blocks are shown graphically in the following diagram:

$B_{i-1,j-1}$	$B_{i,j-1}$	$B_{i+1,j+1}$
$B_{i-1,j}$	$B_{i,j}$	$B_{i+1,j}$
$B_{i-1,j+1}$	$B_{i,j+1}$	$B_{i+1,j+1}$

From this 24 x 24 window, a 10 x 10 window V_{ij}, centered about B_{ij}, is then convolved with a standard Laplacian edge detection kernel G, to give H_{ij}. The edge detection kernel employed is,

$$G = \begin{bmatrix} 1 & 1 & 1 \\ 1 & -8 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

and the convolution is given by,

$$H_{ij} = \sum_{m,n} V_{i-m,j-m} G_{ij}$$

This technique is essentially the discrete equivalent of taking the second derivative of the image in both dimensions. The output of the convolution H_{ij} is scaled to cover an 8-bit range between 0 and 255, the same range taken by the actual pixels in the image. The convolved values are then summed, and the sum is divided by 100*255 to scale the sum to the range 0 to 1. This scaled sum is denoted as K_{ij}. This sum is then renormalized using the following function:

$$Iij = \frac{Kij(100 + C)}{100Kij + C}$$

where C is equal to 14. This function is determined statistically, and remaps the K_{ij} values such that they lie on a normal distribution.

The above procedure is used to calculate I_{ij} for each block in the image. The end result is a value for each I_{ij} which is bounded on the region (0,1), takes values of 0 for flat blocks, and values approaching 1 for blocks that have lots of sharp, short features (in other words have large second derivatives).

The quantization matrix Q is determined at step **46**. In one approach, Q is simply set equal to the standard JPEG quantization table, which is in general use, by the community. An example of a suitable such matrix is the following:

16,	11,	10,	16,	24,	40,	51,	61,
12,	12,	14,	19,	26,	58,	60,	55,
14,	13,	16,	24,	40,	57,	69,	56,
14,	17,	22,	29,	51,	87,	80,	62,
18,	22,	37,	56,	68,	109,	103,	77,
24,	35,	55,	64,	81,	104,	113,	92,
49,	64,	78,	87,	103,	121,	120,	101,
72,	92,	95,	98,	112,	100,	103,	99

In another approach, an image-specific quantization matrix is generated, where the magnitude of each quantization table coefficient is inversely proportional to the importance in the image of the corresponding basis vector.

One approach to generating an image-specific quantization matrix Q defines an 8x8 array such that each value A_{mn} is equal to the sum of the corresponding coefficients (m,n) in each block B_{ij}, weighted by the importance value I_{ij}:

$$A_{mn} = \sum_{\forall(i,j)} I_{ij} (B_{ij})_{mn}$$

After this summation, the matrix A holds relative counts of importance for each basis vector in the DCT transform. This matrix is simply inverted and scaled entry-wise such that

$\bar{A}_{mn} = \max(A_{mn})/A_{mn}$. In the cases where A_{mn} is zero, $\bar{A}_{mn}$ is set to 255, which is the largest allowable value for an 8 bit number. The values in $\bar{A}_{mn}$ are then scaled such that the squared error between $\bar{A}_{mn}$ and the standard JPEG quantization matrix is minimized. The quantization matrix Q is then set equal to this scaled matrix. Note that this process is only performed on the AC coefficients, in other words for all values of (m,n) except (0,0). For the (0,0) entry, Q_{00} is simply initialized to the corresponding value in the standard JPEG quantization table.

Each block B_{ij} is DCT transformed at step **48** according to the JPEG standard to produce DCT coefficients D_{ij}.

For each block B_{ij} in the image, a value S_{ij} is calculated at step **50** where $S_{ij} = I_{ij}*(S_{max} - S_{min}) + S_{min}$. The parameters S_{max} and S_{min} are user specified and in effect define the bounds over which the image will be variably quantized. This method is preferably used to remove redundant data from an existing compressed JPEG by letting S_{min} be equal to the actual scaling value used in compressing the image originally, and using a user-defined value for S_{max}.

Each block B_{ij} in the image is "pseudo-quantized" at step **56** with the quantization table $Q_{mn}*S_{ij}$. This pseudo-quantization in effect emulates variable quantization. If one lets D_{ij} be the original unquantized DCT transformed image block,

and T_{ij} the quantized DCT transformed block at step **54**, then the algorithm for the pseudo-quantization can be described as given next.

The algorithm has three distinct quantization steps. In the first step, the coefficients in the block B_{ij} are quantized using the standard JPEG quantization function with S_{min} as the scaling value:

for each block D_{ij} do

for each coefficient D_{ijmn} in block D_{ij} do

T_{ijmn} = round(D_{ijmn}/(Q_{mn}*S_{min}))

where round denotes rounding to the nearest integer.

In the next step, if any coefficient T_{ijmn} is > 0, then

if round(D_{ijmn}/(Q_{mn}*S_{ij})) = 0 then T_{ijmn} = 0

In the third and final step, if T_{ij} is still greater than zero, and if the coefficient can be rounded down by one logarithm base-2 and not exceed the rounding error introduced by the quantization with the local quantization able, then it is so rounded down:

if (abs(D_{ijmn}) - (2^(ceil(lg(abs(D_{ijmn})+1))-1)-1))

<= abs(D_{ijmn}-Q_{mn}*S_{ij} * round(D_{ijmn}/(Q_{mn}*S_{ij})))

then

$$T_{ij} = \mathrm{sign}(D_{ijmn})*(2\text{^}(\mathrm{ceil}(\lg(\mathrm{abs}(D_{ijmn})+1))-1)-1)$$

In the above calculations, $Q_{mn}*\mathrm{round}(D_{ijmn}/(S_{ij}*Q_{mn}))$ is the reconstructed coefficient after quantization by the local quantization table, and

$$\mathrm{abs}(D_{ijmn}-Q_{mn}*S_{ij}*\mathrm{round}(D_{ijmn}/(S_{ij}*Q_{mn})))$$

is the absolute error introduced by quantization. Furthermore,

$$\mathrm{ceil}(\lg(\mathrm{abs}(D_{ijmn})+1))$$

is the logarithm base-2 of the magnitude of the coefficient, and,

$$(2\text{^}(\mathrm{ceil}(\lg(\mathrm{abs}(D_{ijmn})+1))-1)-1)$$

is the magnitude of the coefficient rounded down by a logarithm base-2.

Thus,

$$\mathrm{abs}(D_{ijmn})-(2\text{^}(\mathrm{ceil}(\log(\mathrm{abs}(D_{ijmn})+1))-1)-1)$$

is the absolute error introduced by rounding down by one logarithm base-2.

The algorithm in its entirety is:

```
for each block D_ij do
{
    for each coefficient D_ijmn in block D_ij do
    {
        T_ijmn = round(D_ijmn/(S_min*Q_mn))
        if T_ijmn > 0 then
        {
            if round(D_ijmn/(S_ij*Q_mn)) = 0 then T_ijmn = 0
            else
            {
            if (abs(D_ijmn) -  (2^(ceil(lg(abs(D_ijmn)+1))-1)-1)) <=
            abs(D_ijmn - Q_m*S_ij * round(D_ijmn/(S_ij*Q_mn)))
            then
            T_ijmn = sign(D_ijmn) * (2^(ceil(lg(abs(D_ijmn)+1))-1)-1)
            }
        }
    }
}
```

The above pseudo-code has the effect of zeroing any coefficients that would have been zeroed if D_{ijmn} were quantized with $Q_{mn}*S_{ij}$, but were not zeroed when quantized with $Q_{mn}*S_{min}$. Also, it rounds down in magnitude (by one power of two) any coefficient that may be so rounded and not introduce more relative error in reconstruction than if that coefficient were truly quantized by

$Q_{mn}*S_{ij}$. This has the net effect of pseudo-quantizing Dij with $Q*S_{ij}$, while actually quantizing the coefficients with $Q*S_{min}$.

Finally, the quantized blocks T_{ijmn} and the global quantization table $Q*S_{min}$ are entropy encoded at step **58** to create a JPEG image file **60** in accordance with the JPEG algorithm while still producing a fully compliant JFIF stream.

It should be noted that the algorithm is particularly useful in optimizing JPEG images that have already been quantized using the standard JPEG quantization table at a level S_{min}. By definition $S_{ij} >= S_{min}$, hence the algorithm guarantees that the optimized JPEG will never be larger in size than the original JPEG, and will in almost all instances be smaller. At the same time the pseudo-quantization ensures that the image quality remains essentially unchanged to the human observer.

For the sake of clarity, the algorithm has been presented assuming the image contains a single 8-bit channel per pixel, in other words it is a greyscale image. However, the algorithm is easily extended to full color (3 channel) images, and more generally, n channel images with few adjustments to the process. In general, the algorithm is simply applied to each channel independently, where the visual importance values are calculated on the luminance channel. A single quantization matrix Q can be employed for all channels, or alternatively, a separate quantization matrix can be used for each channel. Likewise, S_{min}

and S_{max} can either be the same for all channels, are vary from channel to channel.

It is common practice to sub-sample one or more channels when color images are coded. The algorithm can still be employed in this case. An example using a full color, 3-channel image will be described.

A common color scheme to represent a color image is know as YUV. Here, Y stands for the luminance channel (or the greyscale data), and U and V are the blue and red chrominance (color) channels respectively. Since the human visual system perceives luminance information much better than color data, the U and V channels are typically sub-sampled by an integer factor, normally 2, to improve compression. In this case, in the original pixel domain the image is shrunk to half its original size, and then DCT transformed. When decoding, the inverse transform is applied and the plane is expanded by twice its size before merging the three channels to reconstruct the original image.

Because of the subsampling, there may be up to four Y channel blocks that correspond to the same region of an image covered by one U and V block. In this case, the visual importance I_{ij} that is used is simply given as,

max {all corresponding I_{ij} values from the Y channel}.

Referring to Figure **3** the apparatus for JPEG Compression using the above algorithm consists of a frame grabber **80** into which non-overlapping, tiled, 8 x 8 image pixel blocks B_{ij} are stored temporarily. Each block, B_{ij}, the digital cosine transform (DCT) is calculated by DCT transformer **82** and the resultant transform coefficients D_{ijmn} stored in memory **84**. A visual importance calculator **86** calculates values of the visual importance, I_{ij}, for each block B_{ij}. A global quantization calculator **87** calculates elements Q_{ij} of a global quantization matrix utilizing, I_{ij}, and B_{ij}. A linear scaling factor calculator **89** uses user set values of S_{ijmin} and S_{ijmax} set in blocks **124** and **126**, respectively, and I_{ij} to determine S_{ij} in calculator **128** for quantized blocks T_{ij}.

More particularly, values of the quantization matrix Q_{ij} are calculated by first forming the sum of the product of the visual importance I_{ij} and the elements of B_{ij} in block **88** to form the elements A_{mn} in an 8 x 8 array which are stored in memory **100.** The maximum value "Max A_{mn}" in the array is selected by Max A_{mn} selector **102**. The elements Q_{mn} of the quantization matrix Q are calculated as (Max A_{mn})/A_{mn} in block **104.**

In block 106, the quotient of $D_{ijmn}/(S_{ijmin}*Q_{mn})$ is rounded to the nearest integer yielding elements T_{ijmn}. In comparator **108,** the calculated value of T_{ijmn} is compared with zero and, if greater than zero, in block **110** the quotient $D_{ijmn}/(S_{ij}*Q_{mn})$is calculated and

then rounded to the nearest integer. If the quotient $D_{ijmn}/(S_{ij}*Q_{mn})$ equals zero, then T_{ijmn} is set equal to zero at block **112**. If the quotient $D_{ijmn}/(S_{ij}*Q_{mn})$ is not equal to zero, at block **110,** then the value of the rounded value of the latter quotient is transferred to block **116**. Values calculated in blocks **116** and **118** are compared in calculator **120** and if the value calculated in block **116** is less than or equal to the value calculated in block **118,** then the value of T_{ijmn} is set equal to $sign(D_{ijmn})*(2\hat{}(ceil(lg(absD_{ijmn})+1)-1)-1)$. The blocks of quantized coefficients T_{ij} and the global quantization table $Q*S_{min}$ are entropy encoded by entropy encoder **113.**

Accordingly, while this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications of the illustrative embodiments, as well as other embodiments of the invention, will be apparent to persons skilled in the art upon reference to this description. It is therefore contemplated that the appended claims will cover any such modifications or embodiments as they fall within the true scope of the invention.